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Search for the decay $D^0 \to \bar{K}^0 e^+ e^-$

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A search for the decay of the charmed meson $D^0 \to \bar{K}^0 e^+ e^-$ is presented, based on data collected at the $\psi(3770)$ resonance with the Mark III detector at the SLAC storage ring SPEAR. No evidence for this process is found, resulting in an upper limit on the decay branching ratio of 1.7×10^{-3} at the 90% confidence level.

Searches for nonstandard processes such as flavor-changing weak neutral currents[1,2] (henceforth referred to as FCNC's) provide experimental tests of the standard model and its extensions. These currents may lead to decays which, though forbidden in first order in the standard model, can occur at very low rates through higher-order electroweak interactions. A measurement of such a process would therefore provide either an accurate test of higher-order standard-model calculations or indicate the existence of new phenomena as predicted by many extensions of the standard model. Searches for strangeness-changing neutral currents have reached a much higher level of sensitivity to branching ratios than searches for charm-changing neutral currents. It is imperative to search for FCNC's in charmed-meson decays because the couplings involved are usually assumed to be flavor dependent. In some models, studies in D decays can reach sensitivities to coupling strengths which are comparable to those attained in K decays. The absence of helicity suppression in three-body decays, such as $D^0 \to \bar{K}^0 e^+ e^-$ (Ref. 3), is expected to enhance the decay rate relative to two-body reactions such as $D^0 \to e^+ e^-$ (Ref. 4) by about 2 orders of magnitude.[5] We present herein a search for the decay $D^0 \to \bar{K}^0 e^+ e^-$.

The data were collected at a center-of-mass energy of 3.768 GeV, near the peak of the $\psi(3770)$ resonance, with the Mark III detector at the SLAC e^+e^- storage ring SPEAR. The integrated luminosity is 9.35 ± 0.47 pb^{-1}, which corresponds to the production of $53\,600^{+4000}_{-3500}\pm3500$ D^0 (Refs. 6 and 7). As the $\psi(3770)$ lies 40 MeV above $\bar{D}D$ threshold and below $\bar{D}^*D$ threshold, the D's are produced monochromatically, allowing significant background rejection using event selection based on kinematical quantities.

This analysis uses information from the drift chamber, the time-of-flight (TOF) counters, and the shower counter for the electron identification. The TOF system provides rejection of kaons and protons. To distinguish electrons from pions, we employ a sequence of cuts which utilize the TOF measurements and the shape of the shower in the finely segmented barrel shower counter.[8] Within the geometrical acceptance, this procedure, when folded with the expected electron momentum spectrum, rejects 96% of the pions while retaining 83% of the electrons.

All events which contain at least one identified e^+e^- pair are searched for K^0 candidates through the decay $K_S^0 \to \pi^+\pi^-$. For this purpose all remaining charged tracks in the event are treated as pions. All possible two-track combinations are kinematically fitted to a K_S^0 hypothesis. Those with a fit probability $P(\chi^2) > 1\%$, which form a detached vertex more than 2 mm from the primary vertex in the plane transverse to the beam, are considered to be K_S^0 candidates. This procedure has an efficiency of $\sim 40\%$, due mainly to the detached vertex requirement. In order to remove QED background, events are discarded if the K_S^0 and the electron are almost aligned [i.e., $\cos(\mathbf{p}_{K_S^0}, \mathbf{p}_{e^\pm}) > 0.95$]. Event candidates are further required to have an invariant $K_S^0 e^+e^-$ mass within ± 50 MeV/c^2 (two standard deviations) of the nominal D^0 mass.

Sources of background events include $\tau\bar{\tau}$ pair production and radiative Bhabha-scattering events with photon conversion, in which electrons are misinterpreted as pions. Since these events have a lower total charged multiplicity N_{ch} than do charmed events, the total number of charged tracks in an event is required to be at least six. This eliminates background from both sources, while decreasing the number of signal events by 18%. Contributions from continuum production and from two-photon processes are estimated to be less than 0.1 event.

The other sources of background to the decay $D^0 \to \bar{K}^0 e^+e^-$ enter through the misidentification of pions as electrons. Requiring two identified electrons strongly suppresses background contributions from D decays. We expect a total contribution of ~ 0.25 events within the 2σ beam-constrained mass window. These originate predominantly from the decay $D^0 \to \bar{K}^0 \pi^+\pi^-$, when both pions are misidentified as electrons.

After these analysis requirements have been imposed, the beam-constrained mass[9] distribution of the remaining events is studied. Figure 1 shows the expected beam-constrained mass distribution of $D^0 \to \bar{K}^0 e^+e^-$ events, as determined by Monte Carlo simulation. The two shaded bins indicate the two candidate data events whose masses are closest to the nominal beam-constrained D^0 mass. No candidate event falls within ± 5.5 MeV/c^2 of the D^0 mass, which corresponds to two standard deviations of the beam-constrained mass.

The detection efficiency is determined by a combination of Monte Carlo simulation and the use of selected channels in the data sample. To directly obtain the efficiency of the total event particle multiplicity requirement, $N_{ch} > 5$, the multiplicities of the total events are counted for all observed decays in which one D is reconstructed in either of the decay modes $D^0 \to K^-\pi^+\pi^-\pi^+$ and $D^0 \to \bar{K}^0\pi^+\pi^-$, which have the same particle multiplicity as the decay $D^0 \to \bar{K}^0 e^+e^-$. The probability of observing $N_{ch} > 5$, taken as the average from these two modes, is found to be $(81.5 \pm 1.2 \pm 2.6)\%$. The quoted systematic error conservatively reflects variations in the efficiency within the two D decay modes. The efficiencies for the other criteria are determined through the analysis of the Monte Carlo sample. The total efficiency to reconstruct the decay $D^0 \to K_S^0 e^+e^-$ with $K_S^0 \to \pi^+\pi^-$ is found to be $(8.5 \pm 0.1 \pm 0.6)\%$.

The systematic uncertainties in the efficiency include the tracking in the drift chamber ($\sim 1\%$ per track), particle identification (1.8%), and effects of the multiplicity requirement (3.2%). The main source of uncertainty is the total number of produced D's (N_{D^0}), which contributes 7.0% and 6.5% to the statistical and systematic errors, respectively.

As no candidate event has been observed, we determine a 90%-C.L. upper limit on the decay branching ratio based on the total $D^0 \to \bar{K}^0 e^+e^-$ reconstruction

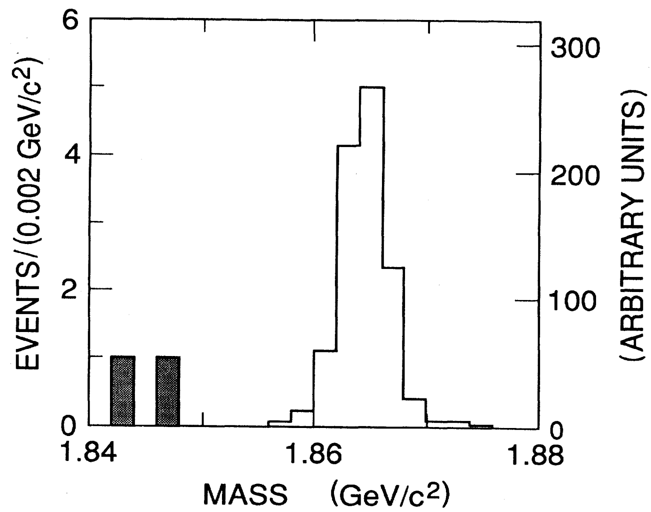

FIG. 1. Beam-constrained mass distribution of Monte Carlo simulated $D^0 \to \bar{K}^0 e^+e^-$ decays, after all requirements have been met. The two closest candidate events from the data sample are shown shaded. No events lie within a $\pm 2\sigma$ range of the nominal D mass.

efficiency of $\epsilon_{total} = (2.90 \pm 0.02 \pm 0.19)\%$. The statistical and systematic uncertainties are combined linearly to obtain 7.4% for ϵ_{total} and 13.5% for N_{D^0} separately, and these total errors are added in quadrature. The inclusion of these uncertainties the Poisson upper limit on the number of events from 2.30 to 2.66, resulting in an upper limit of $B(D^0 \to \bar{K}^0 e^+e^-) < 1.7 \times 10^{-3}$ at the 90% confidence level.

This model-independent limit is consistent with the very low rates ($\sim 10^{-6} - 10^{-8}$) allowed by higher-order standard-model processes, and is similar to other experimental limits.[10] Using particular theoretical models, our limit can be translated into constraints on specific couplings by assuming values for the masses of the mediating particles. For example, in a superstring-inspired phenomenological model,[5] the process $D^0 \to \bar{K}^0 e^+e^-$ can proceed through the exchange of massive color triplets. The limit on $B(D^0 \to \bar{K}^0 e^+e^-)$ then constrains the superpotential coupling strengths (λ_8 and λ_9) between the color triplets and leptons. Assuming masses of 100 GeV/c^2 for the color triplets, one finds λ_8 and $\lambda_9 < 0.5$, respectively. By comparison, in the same model the decay $K_L^0 \to \mu\bar{\mu}(B \sim 10^{-8})$ results in the similar limit $\lambda_9 < 0.6$.

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[3]Throughout this paper, reference to a particle state also implies reference to its charge-conjugate state.

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[9]The beam-constrained mass is defined as $M_{\mathrm{BC}} = [(E_{\mathrm{c.m.}}/2)^2 - \mathbf{p}^2_{\bar{K}^0 e^+ e^-}]^{1/2}$.

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